

Title: THE PROBLEM OF SEPARATION OF GASES BY CENTRIFUGATION (USSR)
Yu. B. Khariton

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CONFIDENTIAL**THE PROBLEM OF SEPARATION OF GASES BY CENTRIFUGATION**

Yu. B. Khariton

Leningrad Inst of Chem Phys

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As may be easily seen, the separation of gases by centrifugation may be conducted reversibly. Therefore this method is a most economical one in principle. For a reversible yield of 1 m³ of pure oxygen and 4 m³ of nitrogen under standard conditions only about 0.09 kw-hr is required - a value much lower than that required by the most perfect and modern equipment.

As indicated by the easy availability of relevant English and French patents (Edoardo Mazza, Fr 756239, Dec 33; Brit 423003, Jan 35) and by reports in technical journals (J. Rabu, L'Industrie Chim. 22, 896, 1935) the method of centrifugal separation is beginning to attract wide industrial interest. The author does not intend here to evaluate in detail this data. It would be time and space consuming and even useless, for the results of computations outlined below prove that these concepts are either illiterate musings or simply technical fakes.

In the present article the author intends to prove that the method considered is entirely inapplicable in cases where huge quantities of gases must be handled - that is from the point of view of practical power engineering. This unsuitability is mostly a consequence of the slowness of the diffusion process.

The amount of gas mixture entering the centrifuge is initially distributed in space according to the potential of the centrifugal force and to the mean molecular weight of the mixture. This distribution occurs nearly instantly - more accurately, in a time interval of the

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same order as the ratio of centrifuge radius to velocity of sound in the given mixture. The distribution is expressed by the familiar formula:

$$\rho = \bar{\rho}_0 \cdot \exp(\mu(\omega r)^2/2RT)$$

(the ρ 's are densities of the gas mixture on the axis of the centrifuge at a distance r from the axis, ω is the angular velocity of the centrifuge, R is the gas constant, T is the absolute temperature and $\bar{\mu}$ is the mean molecular weight of the mixture) Thereafter the mixture begins to separate into components with different molecular weights.

In order that the separation really takes place, perfectly laminar gaseous motion is required: this means that the gas must not be set in motion by a bladed rotor inside an immobile cylinder - that is the cylinder itself must rotate. For a steel cylinder with a strength of 100 kg/mm² a linear velocity of 350 m/sec will produce a stress near the breaking point. Let us assume that such a velocity is attainable. In the case of centrifuging of air introduced near the axis of the centrifuge, the composition in equilibrium near the periphery of the cylinder will contain a little less than 22% oxygen. In order to obtain a mixture with 40% oxygen content, 12 stages of concentration are required. (The variation of C , the ratio of concentrations of the two gases, is computed by means of the expression

$$C = \exp(\mu_1 - \mu_2)V_0^2/2RT$$

where μ_1 and μ_2 are molecular weights, V_0 is linear velocity of the cylindrical periphery, R is gas constant, and T is absolute temperature).

Let us compute now the velocity of separation, the Achilles heel of the method considered (let us again assume that the gaseous mixture, i.e. air, is introduced near the axis of the centrifuge and accordingly condenses at the periphery).

The amount of gas (diffusion stream) $\alpha \left(\frac{\partial \rho}{\partial r} \right)$ flows per second towards the axis through 1 cm² of an imaginary cylinder of radius r , coaxial with the centrifuge (α is the diffusion coefficient and ρ is the partial density of the investigated gas at a distance r from the axis).

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The amount of gas (forced stream) $Ku\rho$ flows under the acting inertial forces from the axis to the periphery through the same cm^2 (K is the coefficient of proportionality and u is the centripetal acceleration). The resulting flow (without consideration of reversible diffusion of nitrogen, which little effects the results) is:

$$q = Ku\rho - \alpha \frac{\partial \rho}{\partial r}$$

The coefficient K may be computed from the condition that for equilibrium, that is when $\rho = \rho_0 \exp \frac{\mu(\omega r)^2}{2RT}$ (ρ_0 is the density of oxygen on the axis of the centrifuge and μ is its molecular weight) the resultant flow q is equal to 0. Hence we obtain $K = \frac{\alpha \mu}{RT}$. Initially ρ is proportional to $\bar{\rho}$ (the composition of the gas has not yet changed); therefore

$$\begin{aligned} q_{init} &= Ku\rho - \alpha \left(\frac{\partial \rho}{\partial r} \right) \\ &= \frac{\alpha \mu}{RT} \omega^2 \rho_0 \exp(\mu(\omega r)^2 / 2RT) - \alpha \frac{\mu \omega^2}{RT} \rho_0 \exp(\mu(\omega r)^2 / 2RT) \\ &= \frac{\alpha \omega^2}{RT} \rho_0 \exp\left(\frac{\mu(\omega r)^2}{2RT}\right) (\mu - \bar{\mu}) \end{aligned}$$

During centrifugation $(\mu - \bar{\mu})$ decreases in such a way that the initial flow is at the same time the maximum flow q_m . Passing to the flow through the total surface of the centrifuge and setting $r = R_0$, where R_0 is the radius of the centrifuge, we shall obtain the maximum (corresponding to an infinitely small concentration) flow of the gas separating:

$$\begin{aligned} Q_m &= 2\pi R_0 l q_m = \frac{2\pi l \alpha V_0^2}{RT} \rho_0 \exp(\mu V_0^2 / 2RT) (\mu - \bar{\mu}) \\ &= \frac{2\pi l \alpha_0 V_0^2}{RT} \rho_0 (\mu - \bar{\mu}) \end{aligned}$$

where V_0 is the linear velocity near the periphery of the centrifuge, l is the length of the centrifuge and α the coefficient of diffusion of the gas investigated in the mixture at the output pressure (coefficient of diffusion is inversely proportional to density of mixture). In the case of separation of air into nitrogen and oxygen if we set $\mu = 32$ and $\bar{\mu} = 28.8$, the linear velocity of the above found value $V_0 = 3.5 \times 10^4$ cm/sec

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and $R = 8.3 \times 10^7$ erg/grad.mol, $T = 300^\circ\text{K}$, $\alpha_s = 0.18$ cm²/sec, we obtain $Q_m = 0.216$. In other words, a separator 1 meter long will give for circumferential velocity 350 m/sec approximately 0.005 g of surplus oxygen per second, or 100 g per hour at infinitely small concentration. A value of the same order is obtained for nitrogen. It means that a nitrogen ~~producing~~ plant producing 100 tons of nitrogen in bound form every 24 hrs would require a centrifuge several hundred kilometers long.

For the case of final concentration this number will still decrease. Somewhat better, but generally just as sad, results are obtained for the separation of pure hydrogen from various mixtures.

The results obtained prove that the installation of centrifugal separators is of no value to the nitrogen industry or for the furnaces employing an oxygen blast. But if only small amounts of gns are required, the centrifugal separator may have some application.

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